Grid Integration of Renewable Energy

Focus on wind energy

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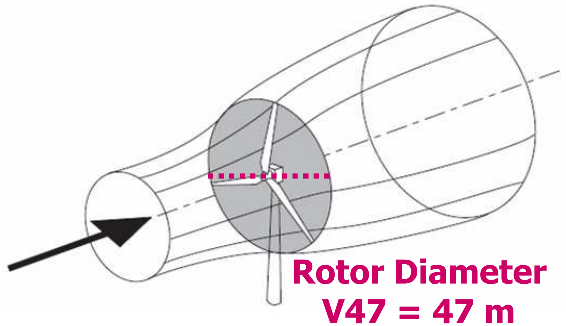
- Wind Energy
- Wind Turbine Technology Types
- Energy production
- Technical considerations
- GTZ-DigSilent studies
- Conclusion

Extract Energy
Expand Vision



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What kind of <u>Distributed or Embedded Generation</u> will be connected to our networks in future?

Wind Energy – understand resource

- **About 1 - 2% of sun energy is converted into wind energy.**
- **About 50 - 100 times more energy converted into biomass**
- **Betz' Law: Maximum energy to extract from wind ~ C_p = 59%**
- **Power max = 0.5 ρ x A x v^3 x c_p**
  - ρ = air density (1.225 kg/m^3, dry, @ 15°C)
    - Temperature, humidity, m above sea level
  - A = Rotor sweep area = $\pi.r^2$ (radius increase)
  - v^3 = Wind Speed cube
    - i.e. Speed x 2 ~ Energy x 8
  - C_p varies
    - 0.5 high speed 2 blade
    - 0.2 – 0.4 slow speed multiple blade
- **Energy = Power x time (E = P.t in kWh)**
- **Energy ~ Roughness / obstacles of terrain**
- **Ideal wind turbine would slow wind by 2/3**
- **Max Efficiency 3 blade ~ 44% at 9 m/s**

Wind m/s 15°C	47 m rotor 660 kW	66 m rotor 1750 kW
1	1.04	2.05
2	8.5	16.8
3	28.6	56.4
4	68	134.1
5	132.2	260.7
6	229.5	452.6
7	364.5	718.8
8	544	1072.9
9	774.6	1527.6
10	1062.6	2095.5

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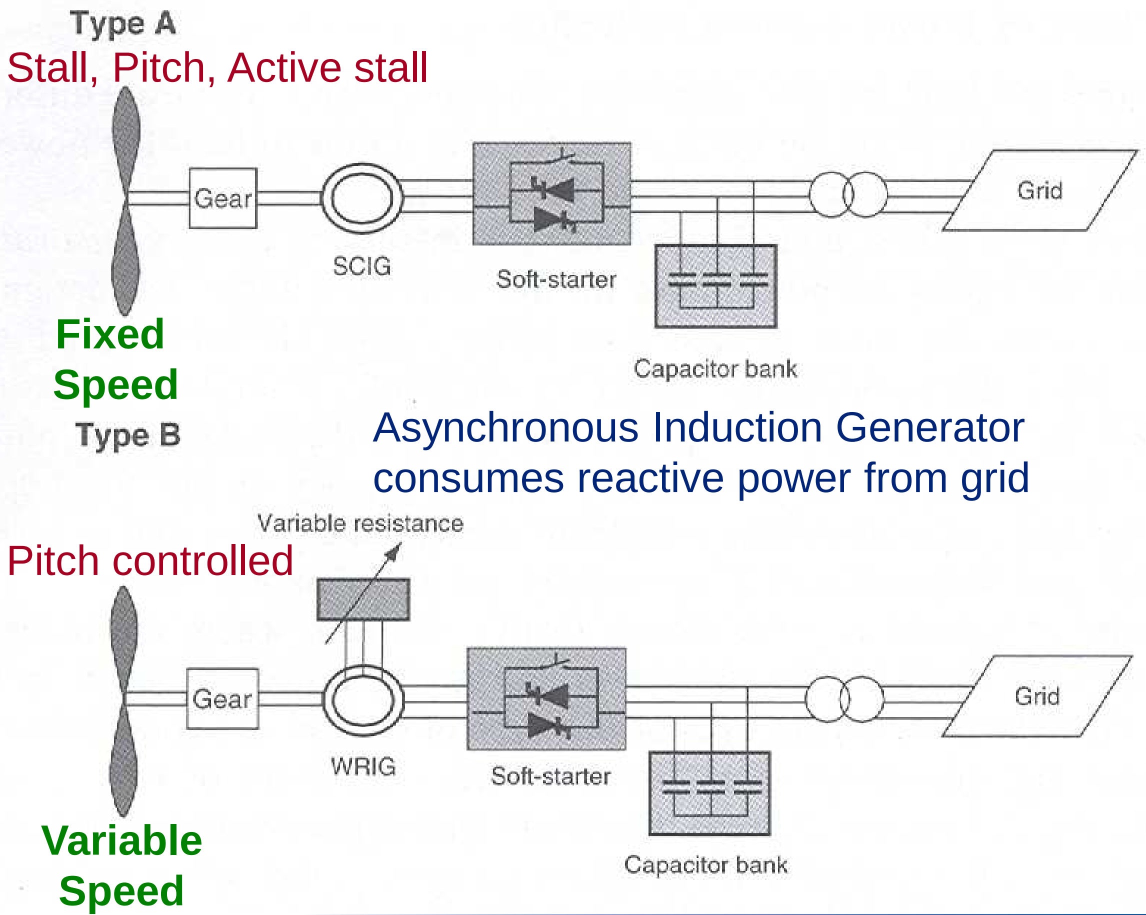
Technology Types

– Model correctly in Power System Analysis (PSA) phase



Squirrel Cage Induction Generator
NOT synchronising, but motor starting

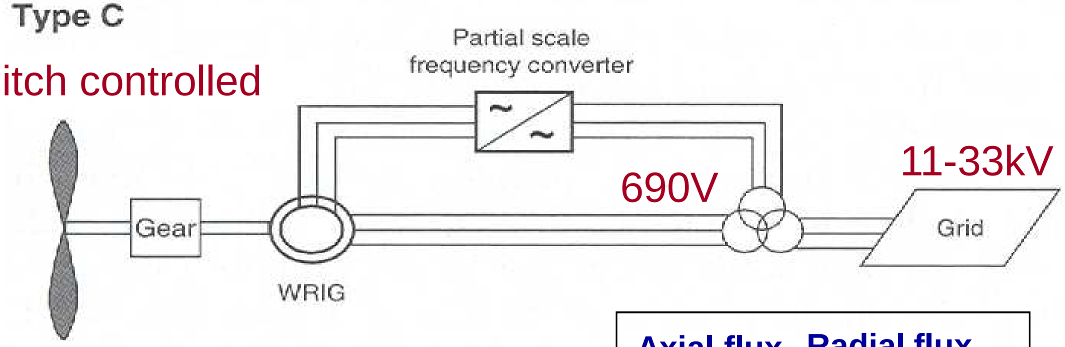
Wound Rotor Induction Generator
(radial flux cylindrical) with e.g. V47 OptiSlip®
Slip may increase to ~10%

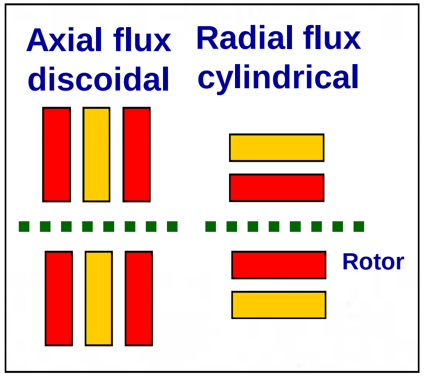
Source: Wind Power in Power Systems

Technology Types – most modern WTG's

Type C

Pitch controlled

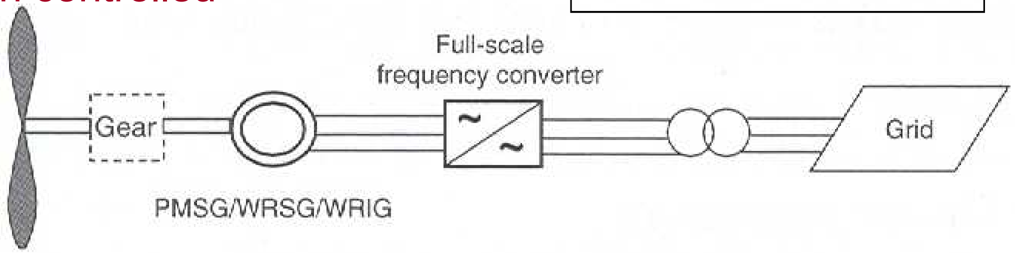




Variable Speed

Type D

Pitch controlled



Wound Rotor Induction Generator
(radial flux cylindrical)
e.g. V66 OptiSpeed™
Slip increase higher to e.g. "~60%"

Low voltage ride through capability

Permanent Magnet Synchronous Generator
(axial flux discoidal)
e.g. J48, Enercon

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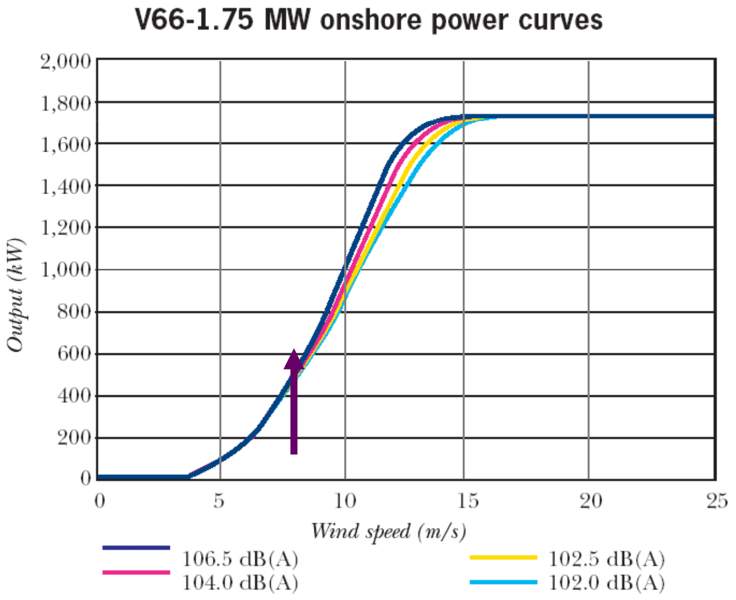
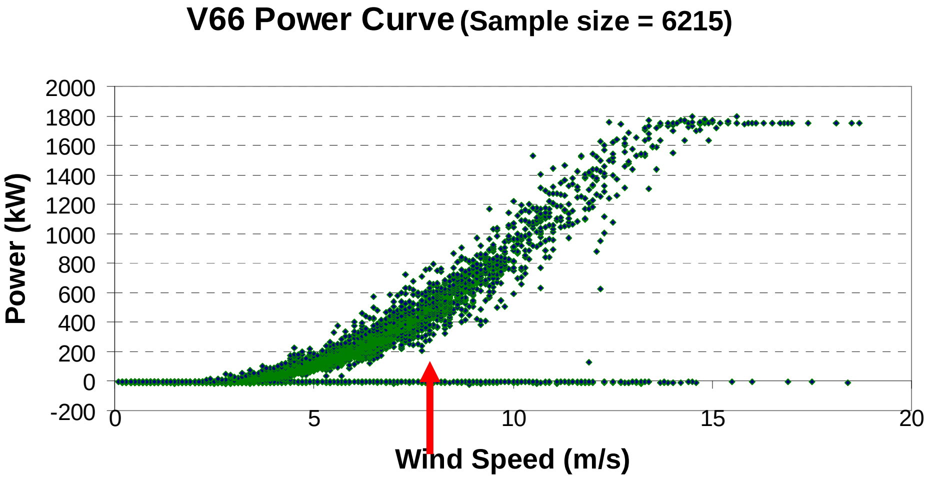
Source: Wind Power in Power Systems

Vestas V66 Power Curves

- Still generate as low as 2.8 m/s wind speed
- Full production at about 12-14 m/s wind (43 – 50 km/h)
- Shut down at 25 m/s wind (90 km/h) (2007: 42.3 m/s on site)
- Production dependent on air density, humidity, etc.





➢**At 375 m with 78 m tower**

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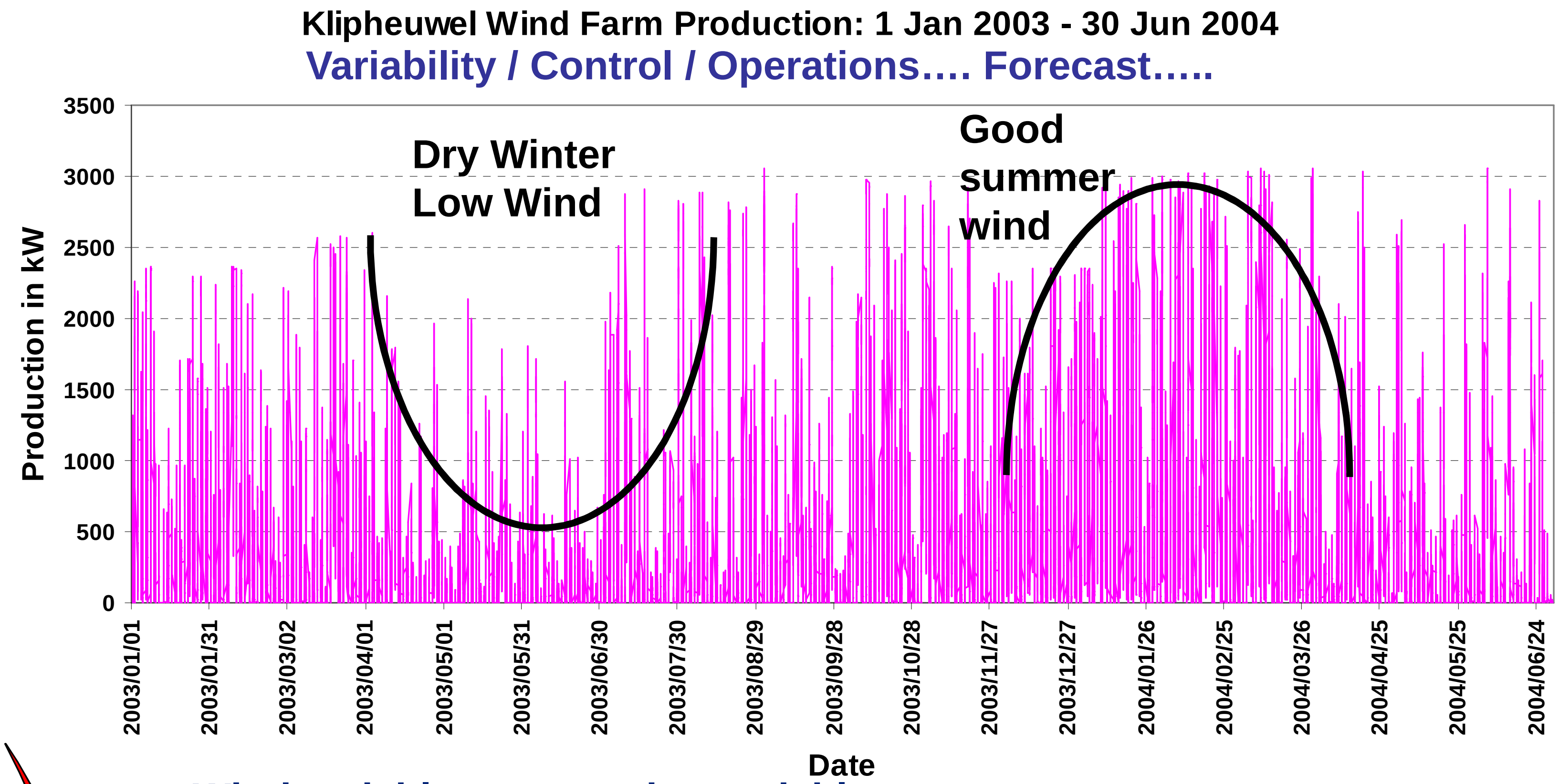
Production profile – site specific



- **Wind variable ~ generation variable**
- **Wind not constant over 24 hr period**

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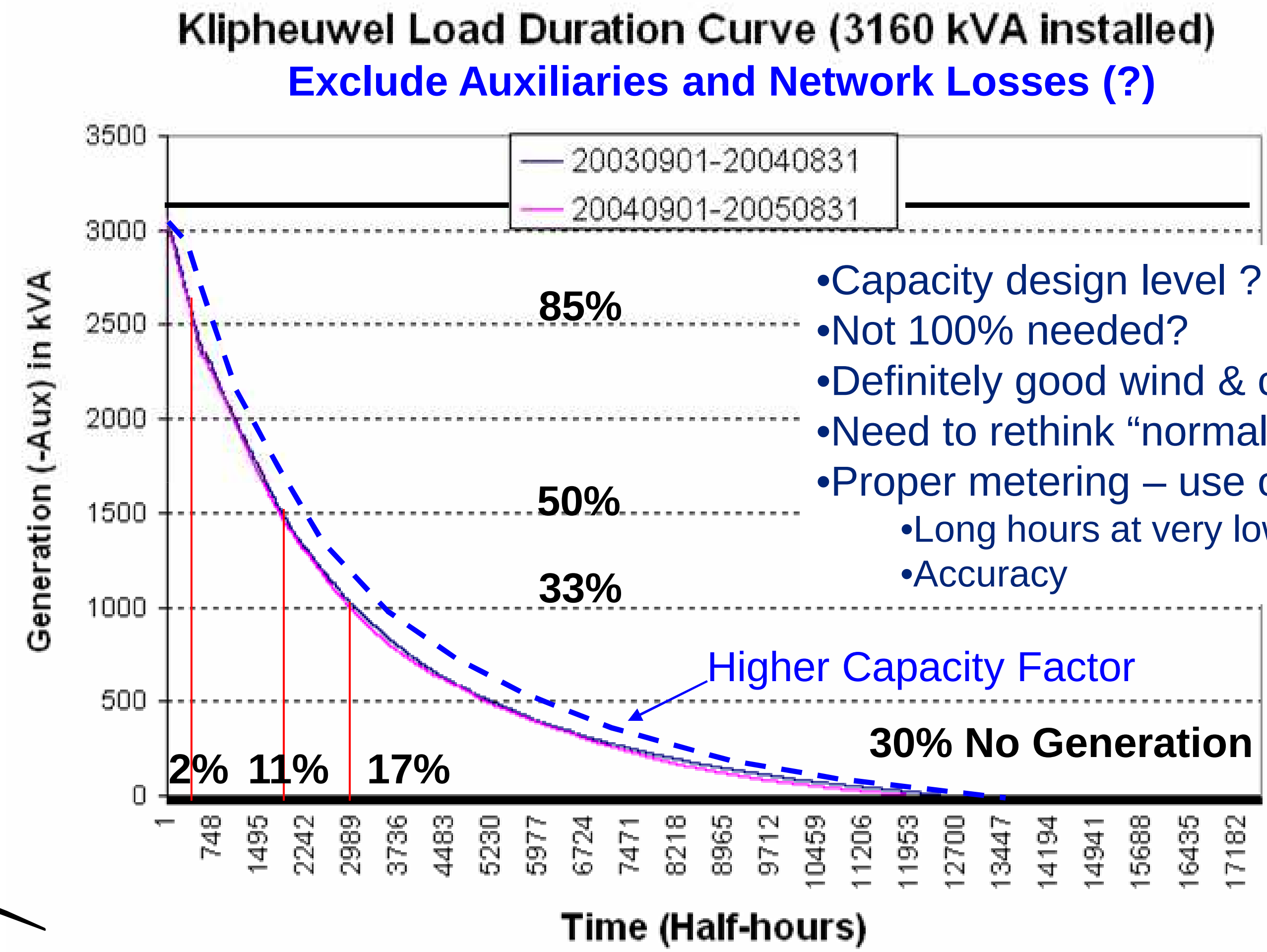
Load duration curve – site specific



- •Capacity design level ?
- •Not 100% needed?
- •Definitely good wind & cooling
- •Need to rethink “normal” limits?
- •Proper metering – use of CT ratio’s
  - •Long hours at very low production
  - •Accuracy

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German Grid Code requirements

- E.ON Netz Grid Code
- Examples of
  - Frequency control
  - Low Voltage Ride Through
  - Reactive Power requirements
- Consider input for South Africa from international Grid Codes

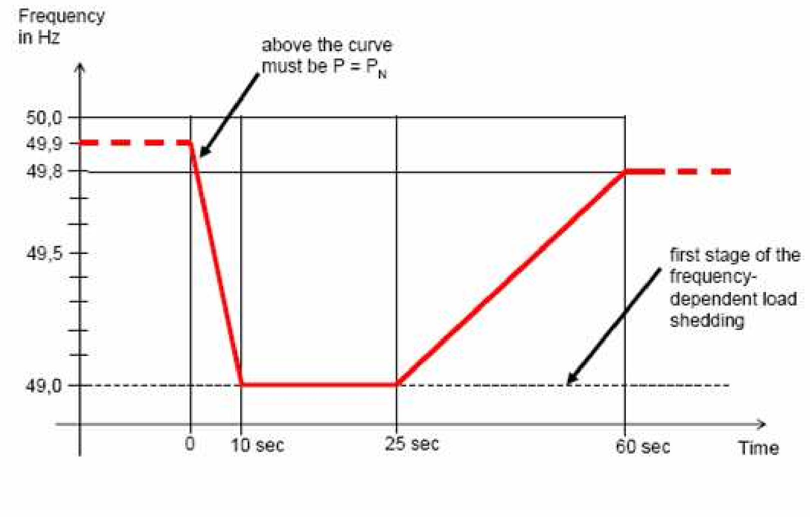


Figure 2 Frequency envelope for frequency drops in which there may be no limitation of the active power output

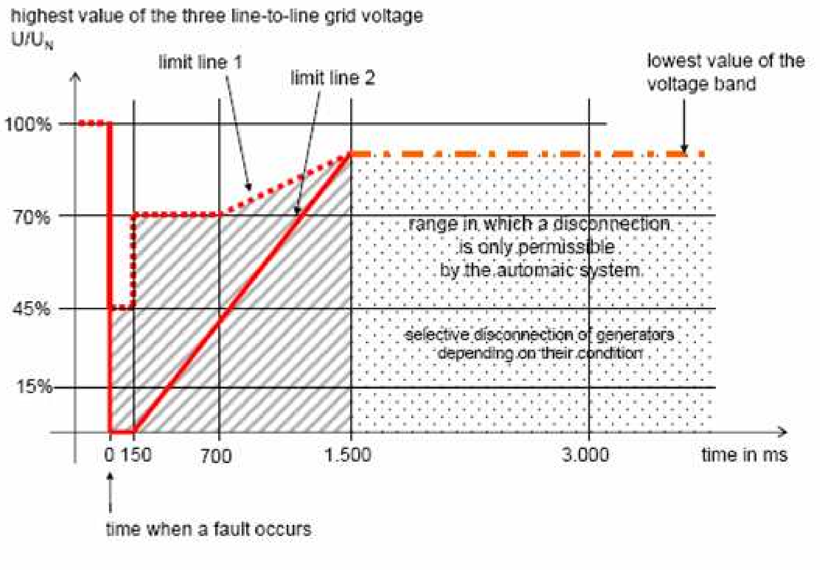


Figure 6 Limit curves for the voltage pattern at the grid connection for Type 2 generating plants in the event of a fault in the grid

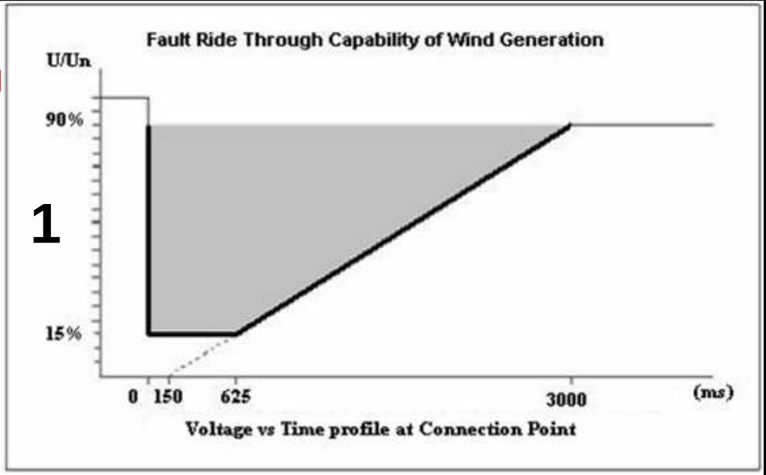
Figure 4 Requirements placed on the reactive power provision of a generating plant at frequencies between 49.5 and 50.5 Hz and without limiting the active power output

LVRT SA Dx Network Code requirem

Low Voltage Ride Through

- *Source = Ireland Dx Grid Code*
- 1. Sub-transmission
- 2. Distribution
- Wind Farm Power Stations shall remain connected to the Distribution System for Voltage dips on any or all phases, where the Distribution System Phase Voltage measured at the Connection Point remains above the heavy black line.

1



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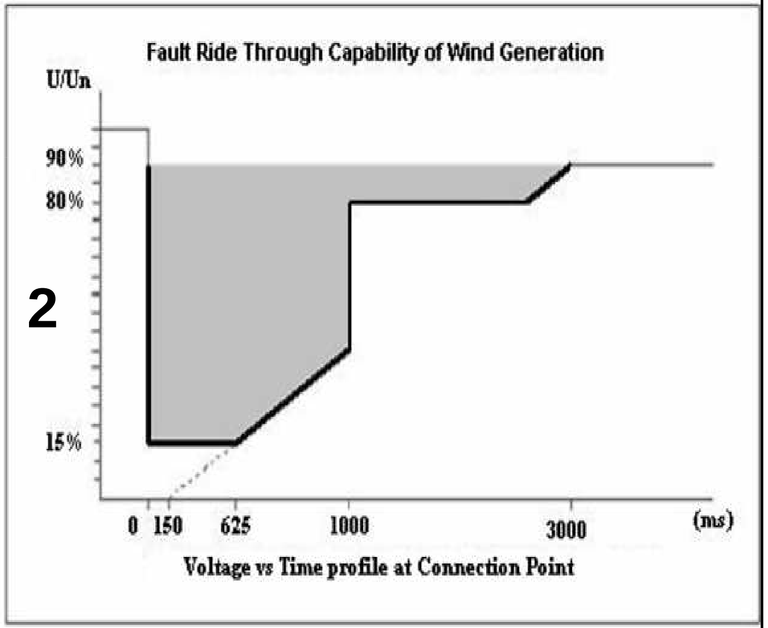

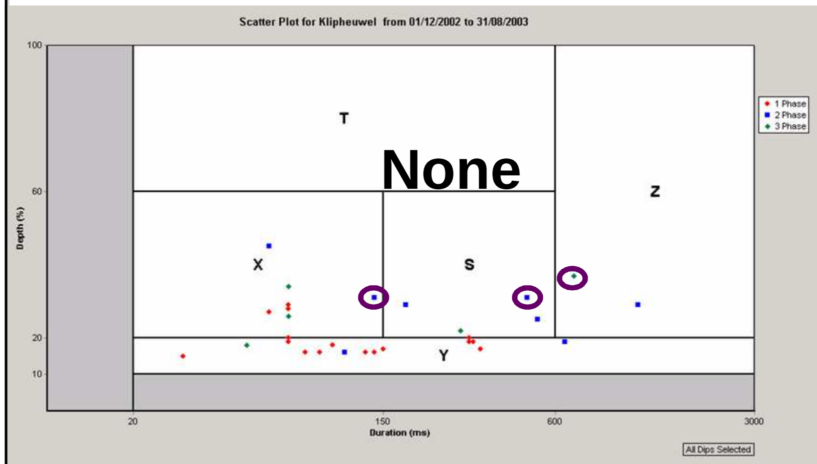

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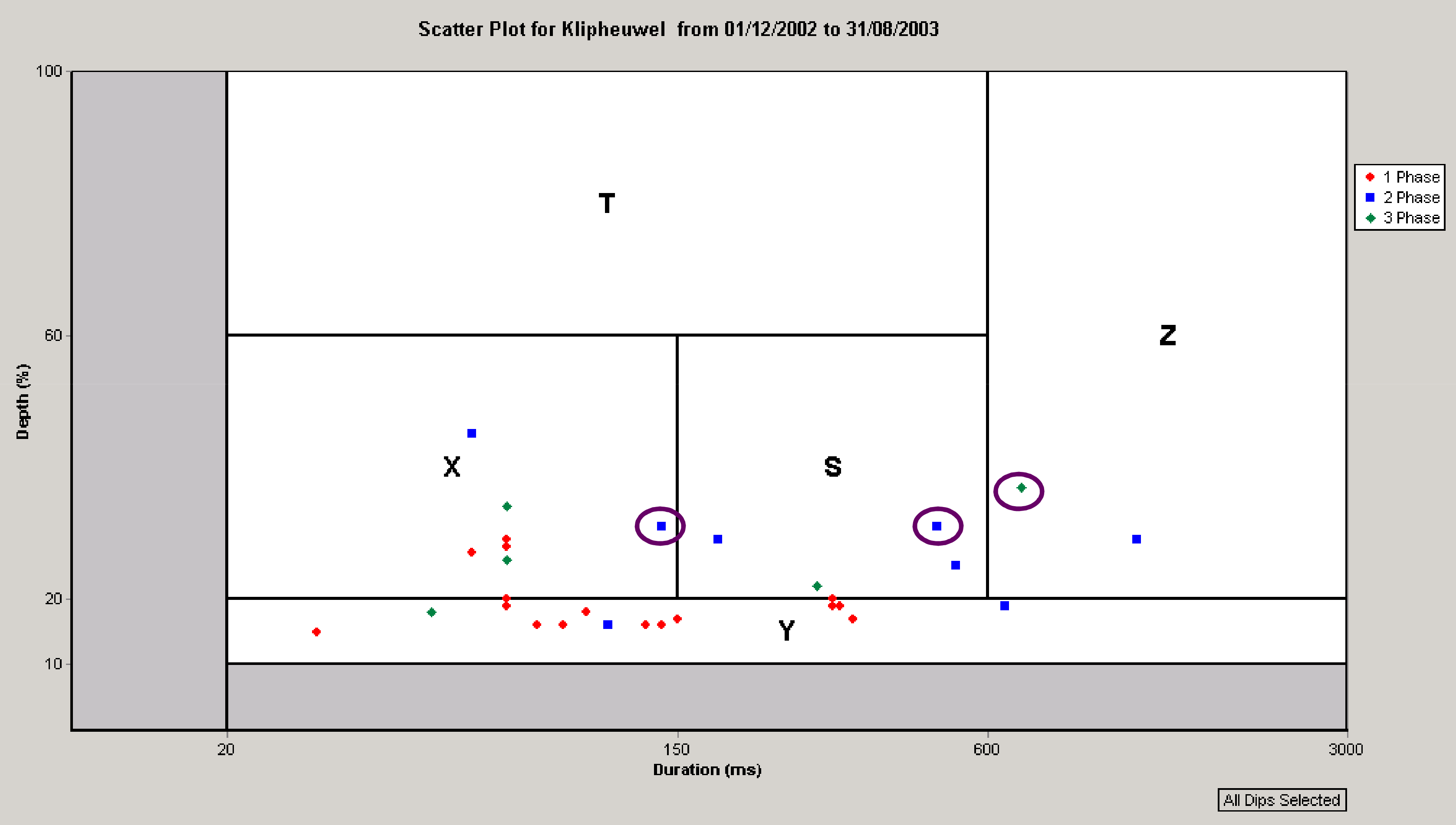
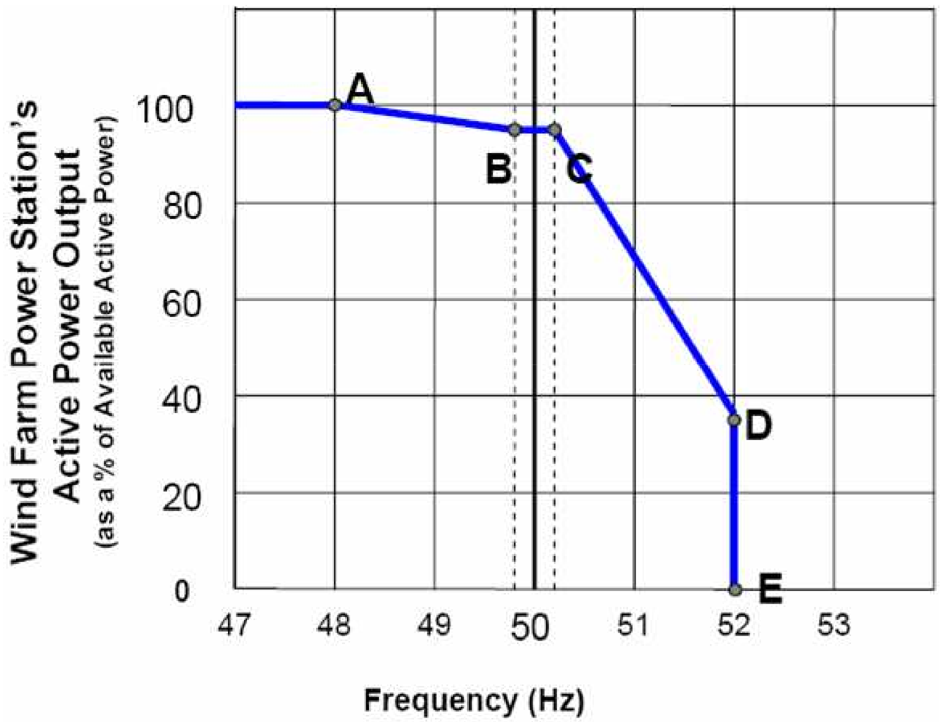
Power System LVRT
Low Voltage Ride Through

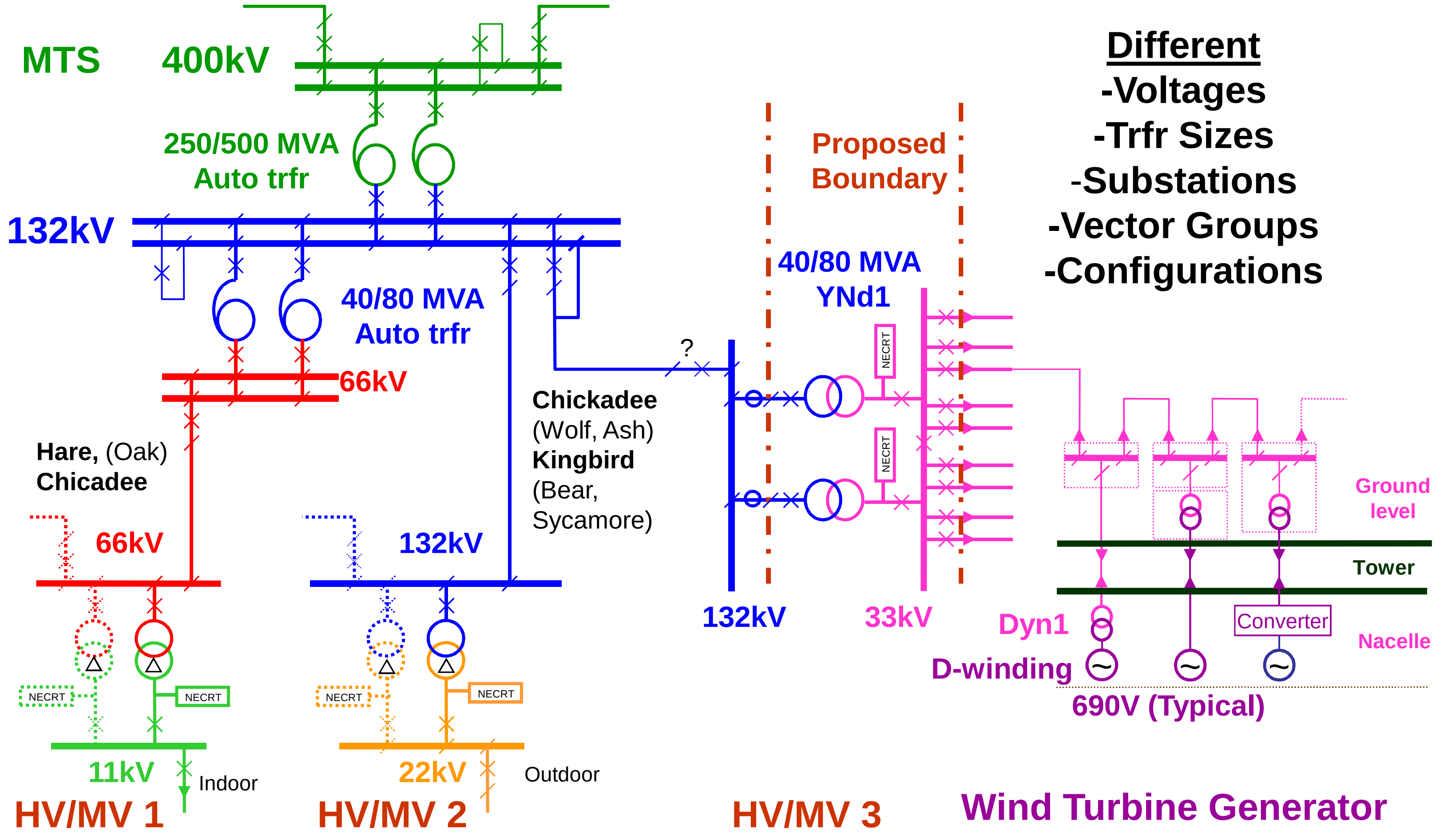


Frequency, Harmonics, Flicker

- *Source = Ireland Grid Code*
- Need for active power control for power frequency control
- Harmonics
  - Power electronics – use on increase (IGBT's etc.)
- Flicker
  - VSC HVDC control up to 3 Hz
  - Reducing WTG flicker considerably, mainly Type A
  - "Slow" – e.g. wind gusts
  - "Fast" – repeated startups, capacitor switching
  - Wave and other energy converters?



Different network configurations



Different
- -Voltages
- -Trfr Sizes
- -Substations
- -Vector Groups
- -Configurations

Please note:
Vector groups are area specific

5/10/20/40 MVA
YNd1 connected as YNd1 or YNd11

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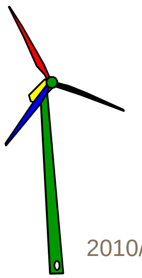
Embedded Generation

- To fulfil Eskom Distribution’s obligation under Section 8.2 (4) of the South African Distribution Code: Network Code:
  - “The Distributor shall develop the protection requirement guide for connecting Embedded Generators to the Distribution System to ensure safe and reliable operation of the Distribution System”.
- DST 34-1765: Distribution Standard for the interconnection of Embedded Generation
- Applicable to renewable energy facilities
- South African grid code requirements for wind energy - draft for comments
- Some special considerations?
  - Disturbs fault current shape, difficult to select overcurrent protection



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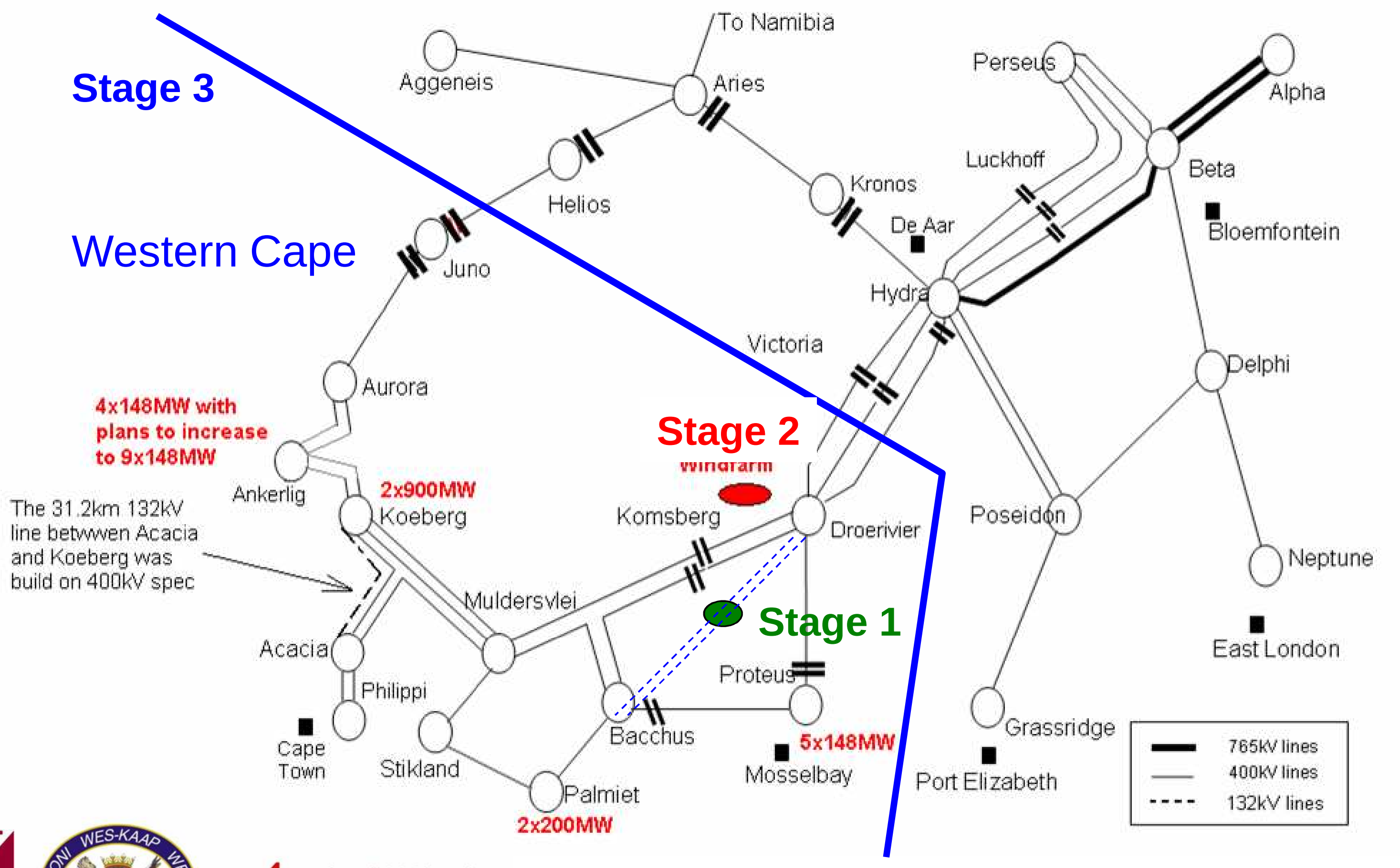
GTZ – D:EADP – Eskom cooperation

- Germany GTZ agreement with Western Cape Province D:EADP
- Eskom participant in agreement
- Cooperation activities
  - 24-25 March 2009 “Grid Integration of Wind Energy” seminar by Dr Markus Pöller, sponsored by GTZ & Western Cape Province D:EADP
  - Invite to Developers, Consultants, Research/Academics, City of Cape Town, Eskom and other role players, e.g. DME & NERSA
  - 26-27 March 2009 Eskom Wind Energy Workshop to create scenarios for:
    - 150 MW case study on sub-transmission network
    - 750 MW case study for integration into 400kV network, incl. 132 kV
    - Regional study of ±2800 MW on larger main transmission system
  - 14-15 May 2009 Cape Town Workshop 2
  - 22-24 July 2009 Follow up session to evaluate feedback
  - 24 July 2009 Feedback on high level grid scenarios and various technical studies, in cooperation with DigSilent (sponsored by GTZ)
  - 9-13 Nov 2009 Berlin Conference & Training opportunity
  - 24 Nov 2009 Cape Town Workshop 4

Transmission System



Stage 1: 150MW near to Laingsburg

- Impact on thermal limits in the surrounding distribution network
  - Identification of possible Issues
  - Mitigation options
- Impact on voltage variations at the connection point and the surrounding distribution system:
  - Required reactive power control method (const power factor, voltage control, fast/slow voltage control, droop control....)
  - Required reactive range of wind farm for maintaining the voltage.
- Impact on short circuit levels
- Impact on Power Quality aspects
  - (Harmonics/Flicker, IEC 61400-21)

Transfer limitations

As line length increases

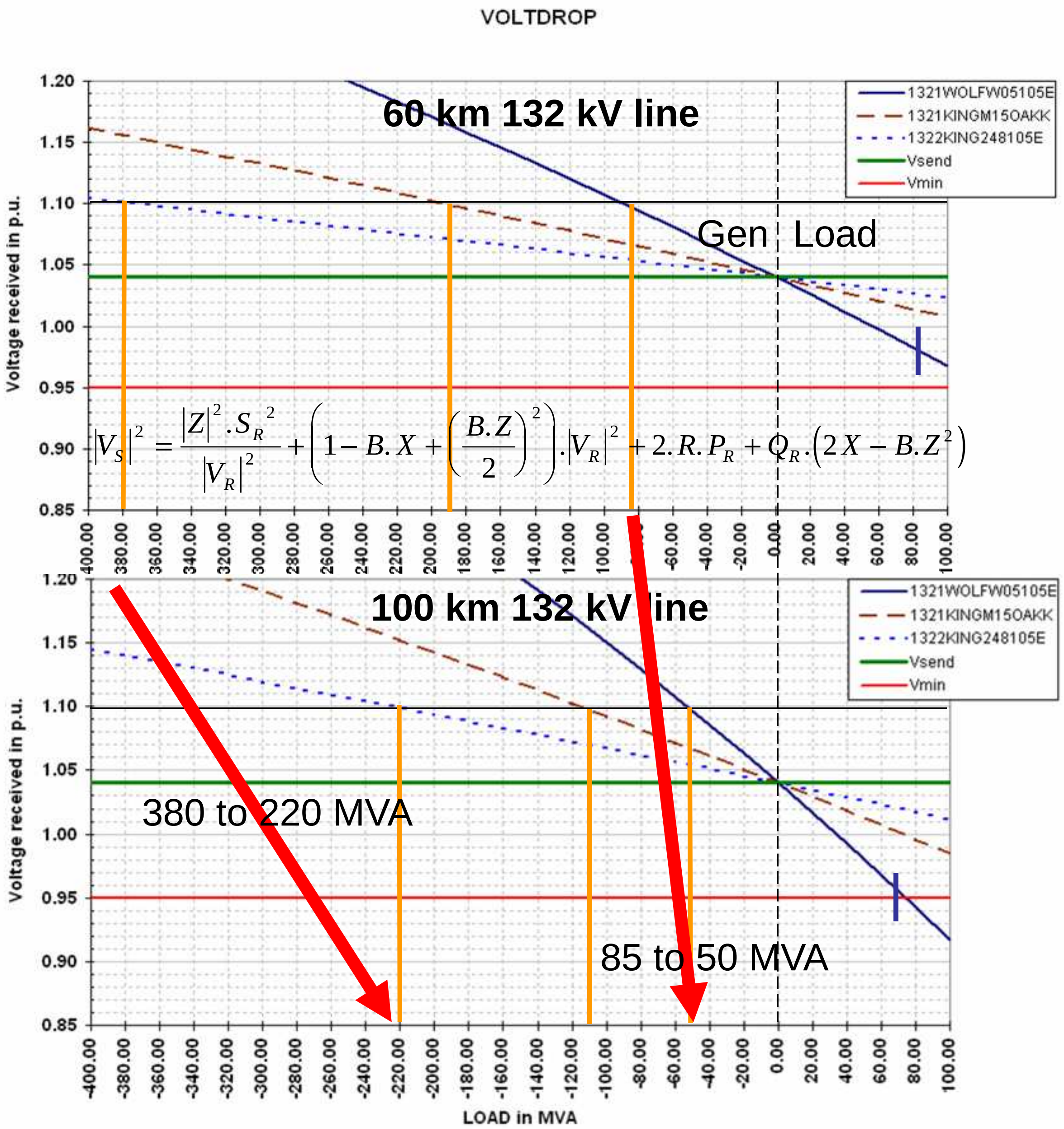
- Increase in losses
- Voltage changes
- Limit transfer Capacity

New infrastructure

- Choice of voltage
- Select conductor size

Steady state load flow

- PowerFactory simulations



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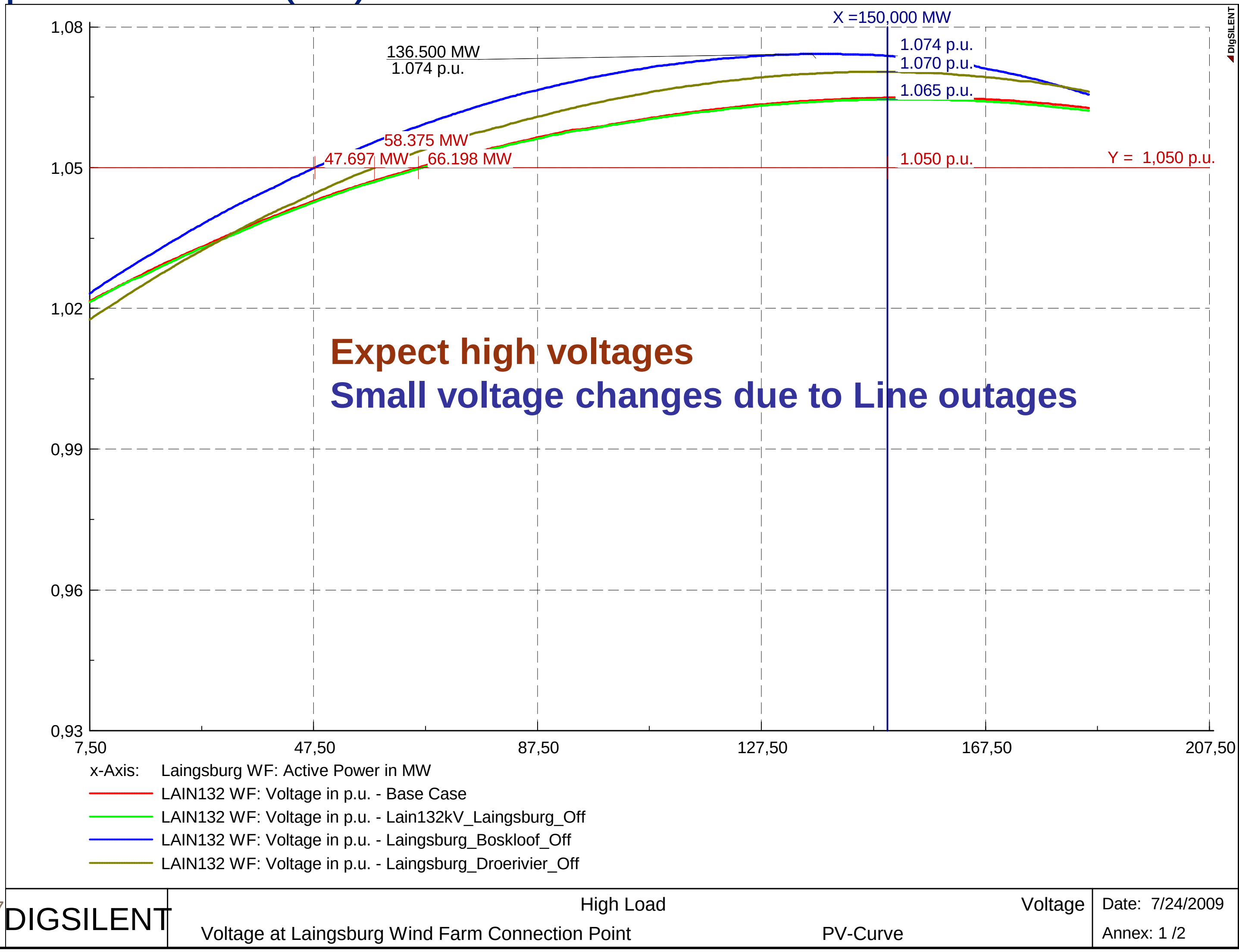
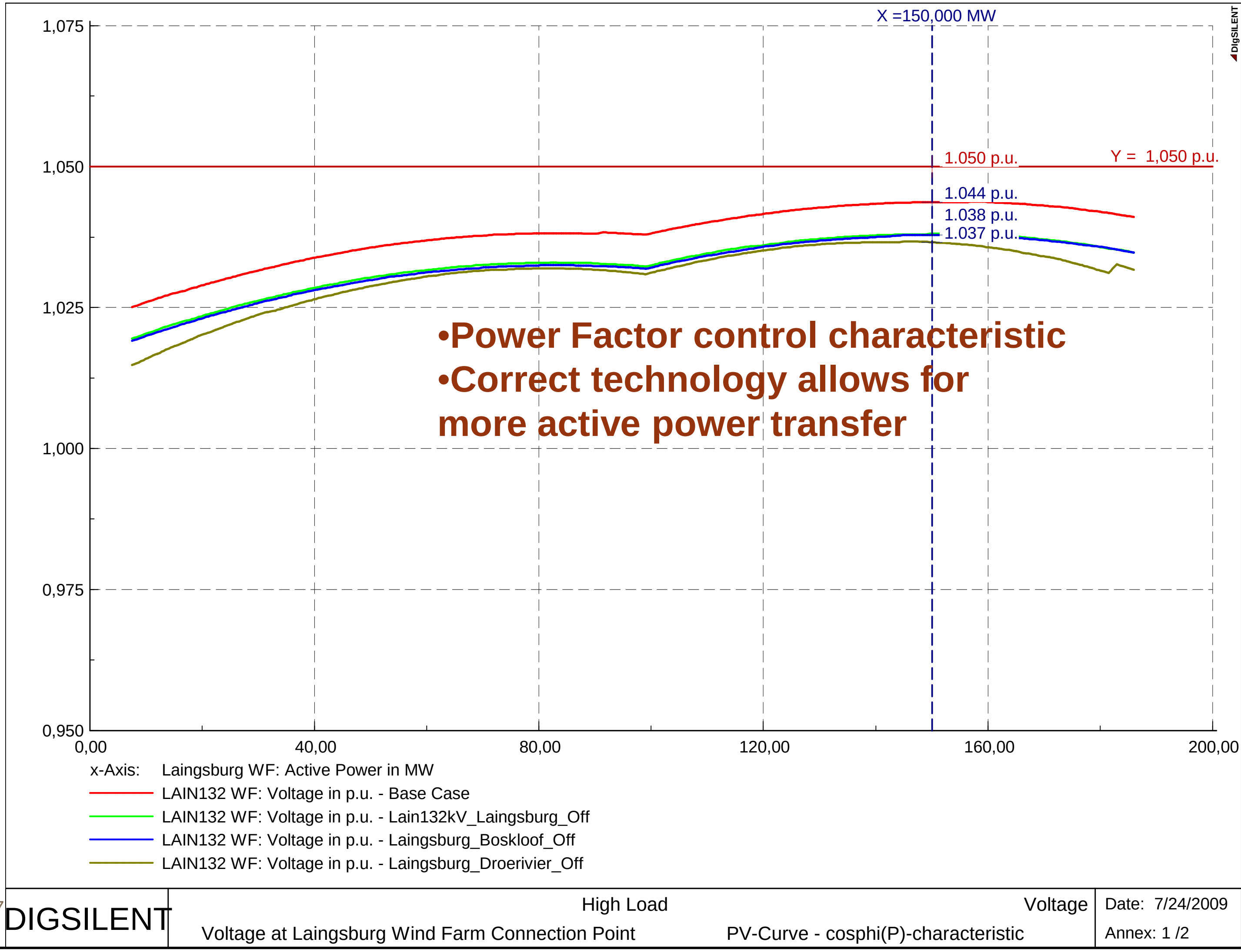
Voltage Variations

– cos phi constant (=1)



Voltage Variations

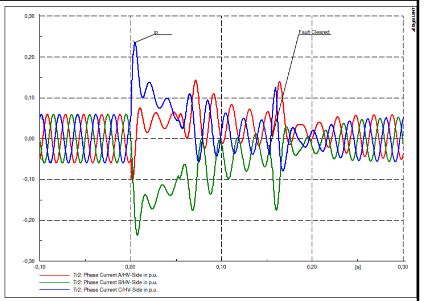
– cos phi(P)-characteristic



Voltage Variations - Summary

- High voltages in case of cos(phi)=1
- Small voltage variations if cos(phi) adjusted to actually generated power.
- Voltage control at wind farm connection point is possible but not required in this particular case
  - slow voltage control is standard requirement in Germany.
- Voltage control must be seen as ancillary service that stabilizes the grid and secures the grid against voltage collapse in case of major disturbances.
- But: Typically voltage control capability of wind farms not available in case of zero power output (vw<vw_cutin).

Impact on Short Circuit Currents



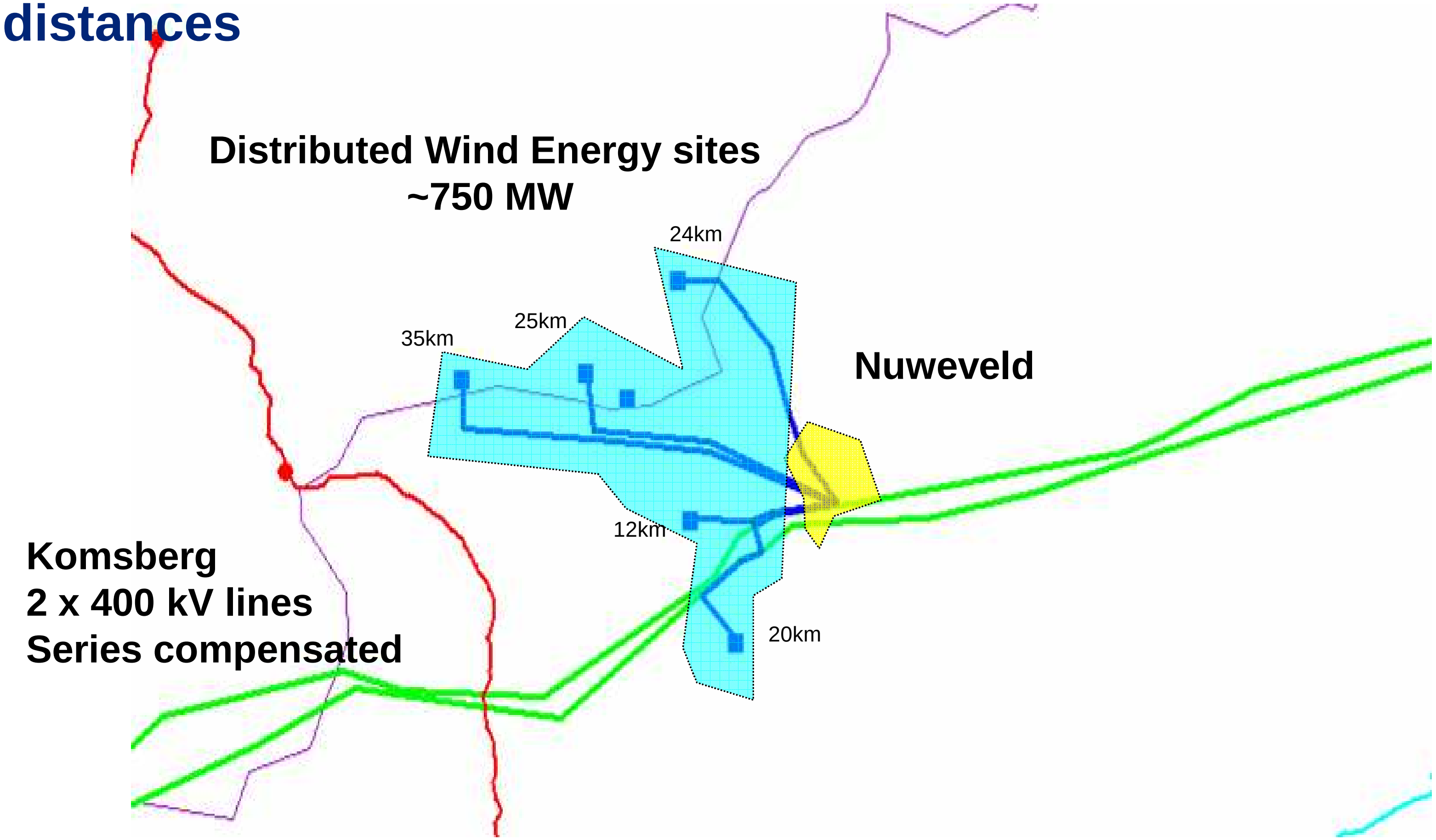
- **DFIG**
  - Considerable contribution to peak short circuit current.
  - Contribution to thermal short circuit ratings: approx 1 p.u. shc-current
- **WTG with fully rated converter**
  - Contribution to initial short circuit current: approx. 1 p.u. shc-current
  - Contribution to thermal short circuit ratings: approx 1 p.u. shc-current
- **150MW wind farm at Laingsburg**
  - Contribution to initial shc-current (Ikss): approx 2 kA (at 132kV)
  - Contribution to peak shc-current (ip): 4,4 kA
  - Contribution to transient shc-current (Iks): 0,67 kA
- Contribution to fault levels not critical in this particular example because of low fault level at wind farm connection point.

Impact on Flicker and Harmonics

- Analysis of Flicker and Harmonics using IEC 61400-21 data sheet of a typical variable-speed wind generator.
  - Flicker: Pst = 0,066 / Plt=0,08
  - Harmonics: THD=0,75%
- Flicker generally low in case of large wind farms because Flicker-relevant turbulences within a wind farm are only weekly correlated
- Harmonics of modern wind turbines (with IGBT-converters) very low. Almost no harmonic current injections.

Stage 2 – 750MW of Wind Gen in Karoo

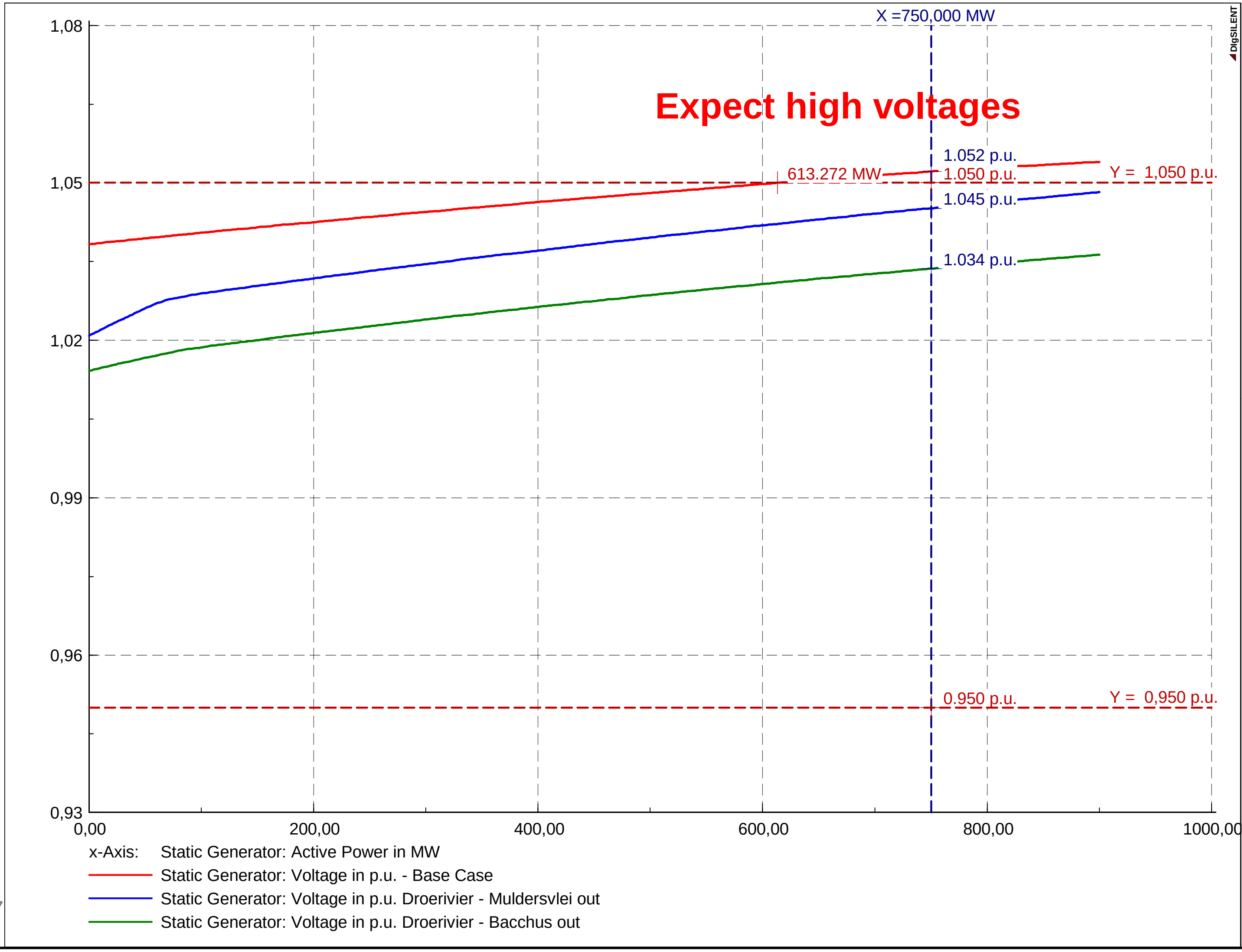
Represent a group of green field projects within reasonable distances



Stage 2 – 750MW – Scenarios for Studies

- System 2009 (without new 765kV running into the Cape)
- Analysed cases
  - High load, 1x Koeberg unit in
  - High load, 2x Koeberg units in
  - Low load, 1x Koeberg unit in
  - Low load, 2x Koeberg units in
- Generation Balancing / High Wind
  - Reduction of Gas Turbine Generators (running in SCO mode where possible)
  - Reduction of pump storage generation at Palmiet
  - Reduction of coal power plants outside the Cape

Stage 2 – 750MW wind in Karoo - Voltages



Stage 2 – 750MW – Summary of Results

- No thermal overloads under n-1 conditions
- Voltage variations very small, even in constant power factor operation.
- Operation with constant Q (var-control) is appropriate.
- (Slow) voltage control is possible and should be considered.
- 4x100Mvar shunt reactors required at Nuweveld substation (or equivalent var-absorption of the wind farms) because of proximity to Komsberg series compensation.
- Series compensation at Komsberg should be resized for considering new line configuration.
- With adjusted series compensation, shunt reactors at Nuweveld might not be required.
- No power quality issues because of the large number of turbines and high fault level at the grid connection point

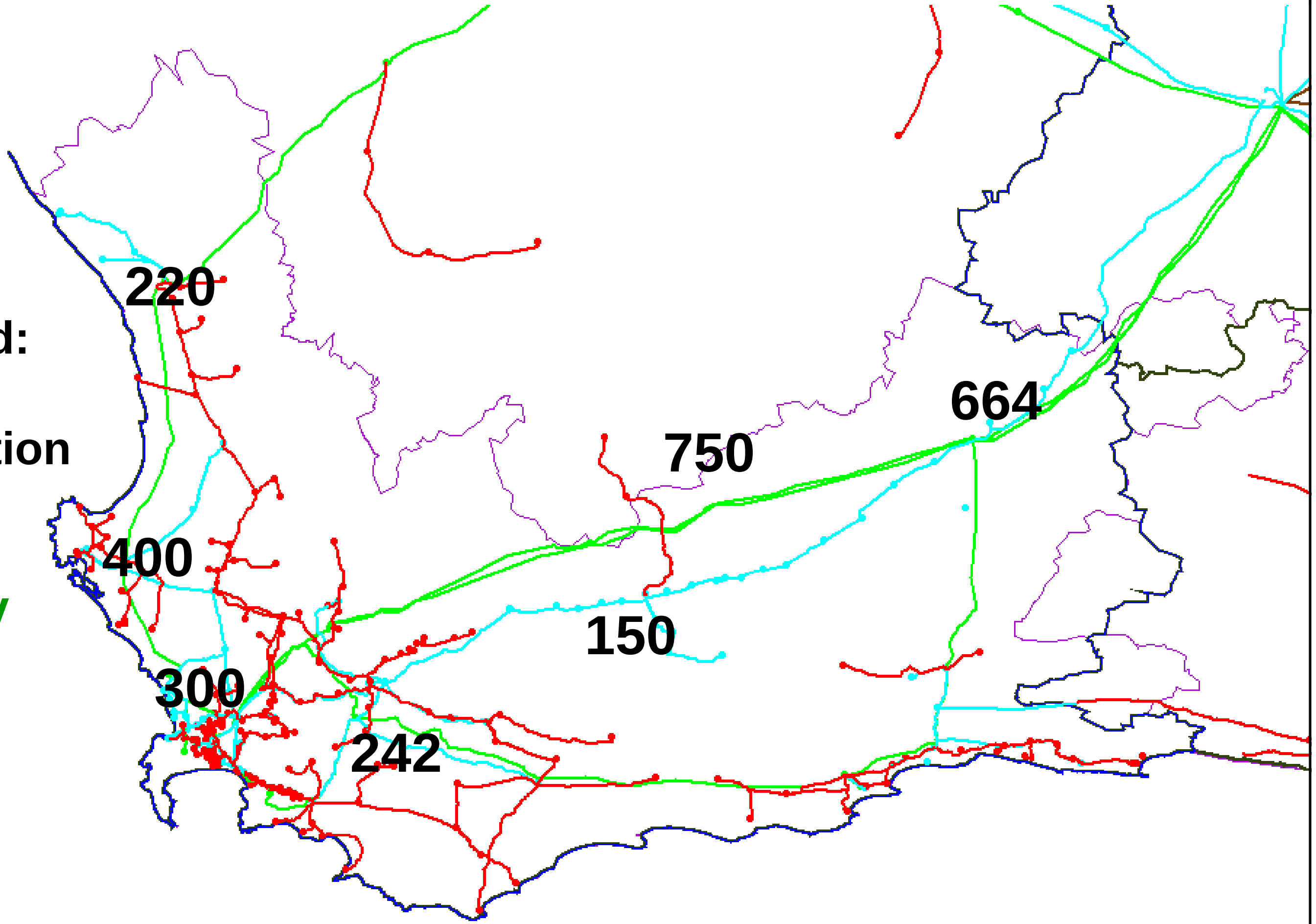
Stage 3 – 2800MW of Wind Gen in the Cape

- Consideration of all wind farms in the Western Cape, for which application exist (2798MW by end of March 2009)
- High level feasibility studies considering the existing ESKOM transmission grid (excluding sub-transmission, <=132kV)
- Constraints:
  - No major network upgrades (such as new 400 kV lines)
  - Minor network upgrade, such as additional var-compensation is allowed.
  - Lump load in respective areas at current MTS substations
    - Ignored installed transformer capacity
- System 2009 (without the new 765kV line running into the Cape)

Stage 3 – 2800MW Generation distribution

Scenario tested:

As per application Requests
- 2009-03-26
Load on 400 kV
Transformer capacity may be required



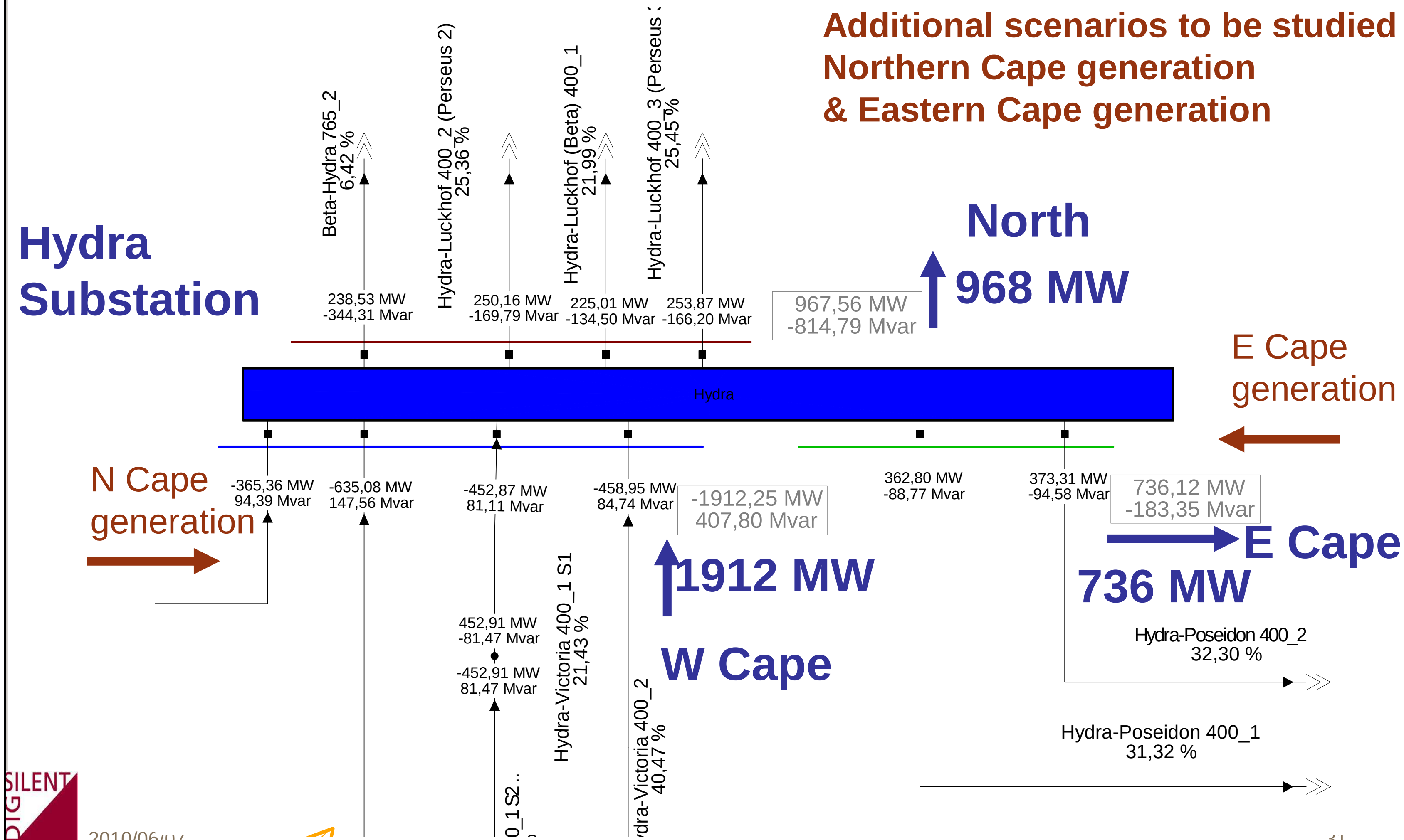
Stage 3 - 2800MW – Scenarios for Studies

- Consideration of all wind farms in the Western Cape, for which application exist (2798MW by end of March 2009)
- Assumption: Max. wind generation = installed generation -> overestimates max wind generation by 10..20%, leaving some margins.
- Analysed cases:
  - **High load, 1x Koeberg unit in**
  - **High load, 2x Koeberg units in**
  - **Low load, 1x Koeberg unit in**
  - **Low load, 2x Koeberg units in**
- **Generation Balancing – High Wind Scenarios:**
  - **Reduction of Gas Turbine Generators (running in SCO mode where possible)**
  - **Reduction of pump storage generation at Palmiet**
  - **Reduction of coal power plants outside the Cape**

Stage 3 – 2800MW of Wind

Example: Low Load + High Wind, 2xKoeberg units

Additional scenarios to be studied
Northern Cape generation
& Eastern Cape generation



What else needs to be done

- Additional, more detailed studies at transmission levels, including additional generation-load scenarios and alternative wind generation scenarios.
- Stability studies under various operating scenarios.
- Wind farm connection studies for every wind farm application.
- Studies related to transmission system operation under situations, in which the Cape exports power to the rest of the system
- Studies related to the expected total power variations of wind generation (variations, ramp-up and ramp-down speeds) for identifying additional reserve requirements have to be carried out.

Conclusion

- Good cooperation by developers
- REFIT 1 & 2 available
- DoE IRP 1 available
- Await DoE RE targets MW/Technology
- DoE IRP 2 will help dictate vision that will help shape infrastructure
- Await NERSA selection rules & criteria
- RFQ - RFP - PPA?
  Quotes for serious projects
- Renewable Energy Development Areas being studied – to motivate long term grid solutions
- Expectations high

The challenge is on for us in SA to make it work – we can do it!

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Thank you

- Also to Eskom for attending the SIDA – Life Academy "Wind Energy Development and Use" course, 12April – 5 May 2010 in Sweden
- See www.Life.se for more info on 2011 course